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THERMAL INFRARED USERS MANUAL

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SUMMARY

ve been utilized by the Forest Service and other
t and other purposes for about 20 years. A
g from simple, low capability instruments to
tems involving a variety of engineering
e. These can be applied most effectively when the capabilities and limitations of each are recognized and considered. Often a combination of the various types are required to accomplish the necessary reconnaissance missions. Thermal infrared is usually considered to be in two unique bands of the electromagnetic spectrum. Proper usage of instruments can provide critical information about fire which cannot be obtained by visual or any other known surveillance methods. The use of this information, applied by knowledgeable personnel, continues to be invaluable for many fire management activities.

THERMAL INFRARED USERS' MANUAL

Table of Contents

TABLE OF CONTENTS (Cont.)

I. INTRODUCTION

This manual provides a basic overview of many of the considerations involved in the selection and use of thermal infrared (IR) equipment/systems for fire management needs. It contains a brief discussion of IR characteristics, types of IR equipment and systems, examples of available IR resources, operational considerations, capabilities and limitations, and other reference material. IR equipment ranges from simple, limited capability handheld devices to technologically complex systems involving a variety of engineering disciplines and areas of expertise (see Appendix 1). The Infrared Handbook[1] contains over 25 chapters and 1700 pages written by specialized experts from academia and industry, most with PhD's and many years of experience. Beyond the basics provided in this manual, additional technical consultation and training are available from the Aviation & Fire Management (A&FM) Advanced Electronics Systems Development Group stationed at the Boise Interagency Fire Center (BIFC).

II. BACKGROUND

The existence of the infrared region of the electromagnetic spectrum was discovered by Sir William Herschel in 1800.[2] The development of practical systems was mainly for use in military applications. Use of IR prior to World War II was limited because many present applications were not envisioned but also because optical materials, filters, sources, detectors, and other technologies were not sufficiently advanced to permit useful scanning devices. Many techniques and components were available in the post-war period because of German emphasis on military IR technology. The period up to 1950 did not produce a large number of systems, but created interest in infrared applications and producing improved detector materials, a variety of optical components and other related technical advances.[3] From 1950 to 1960 a number of IR scanners, including search systems, tracking systems, and mapping/imaging systems were built and many scanning and other techniques were developed. Forest Service research into infrared applications for fire management started in the early 1960's and operational infrared line scanning systems have been in use since the early 1970's.[4] Since the later 1970's, handheld IR imaging devices, including forward looking infrared (FLIR) units, have been adopted for fire applications.

III. TECHNICAL FEATURES

A. The Electromagnetic Spectrum - Figure 1 shows the electromagnetic spectrum and the relative positions of the visible and infrared portions of the spectrum. Note the very small portion (visible) that our eyes can sense. Virtually everything that we see (sense with our eyes) is sensed via reflected energy in the visible portion of the spectrum. Infrared film senses energy near the visible spectrum to about 1 micrometer wavelength, thus extending our natural eye sensing. Various physical phenomena can be observed in that extension which are not visible to the eye. Thermal infrared systems do not record directly on film. They do not use "cameras" per se, even though they are sometimes called cameras and often erroneously reported as such by the news media. See Appendix 2 for some additional discussion. The thermal infrared bands commonly used in all thermal

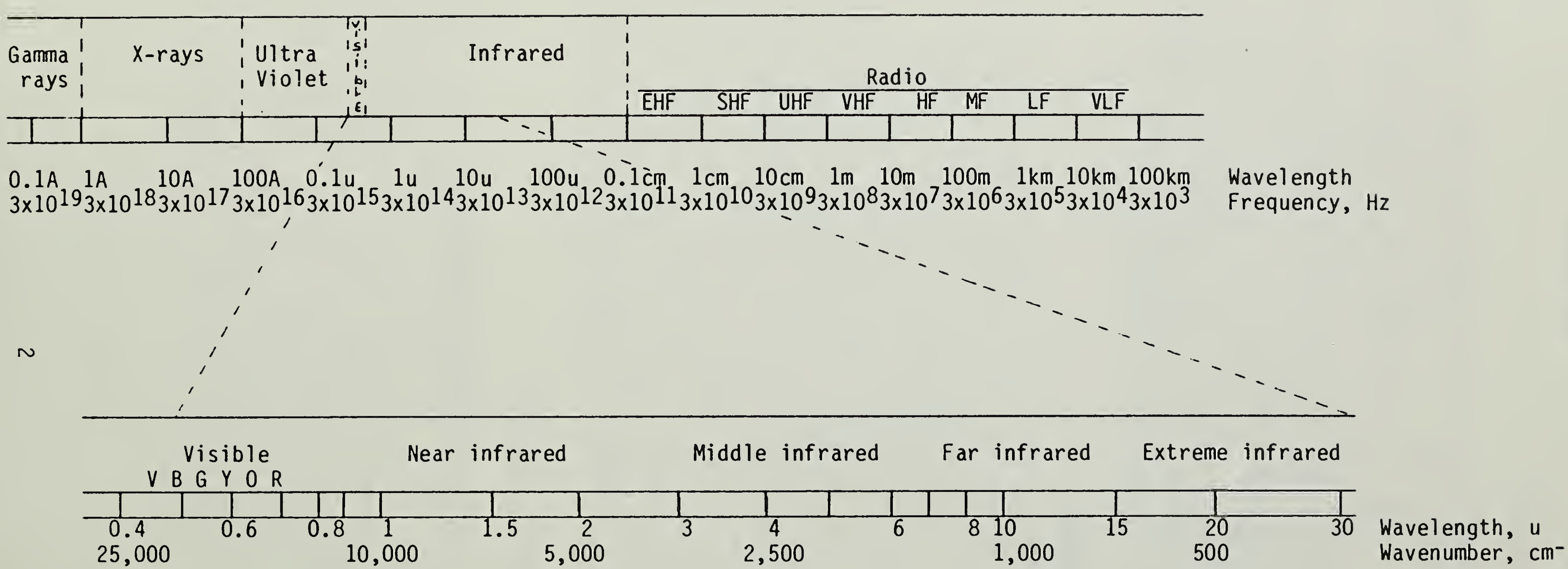

Figure 1 The electromagnetic spectrum

infrared systems are approximately 3 to 5 micrometers and 8 to 14 micrometers. Those two bands are usable for sensing because of their atmospheric transmission characteristics and they are useful because the 8-14 energy level peaks at ambient earth temperatures and the 3-5 peaks at higher temperatures related to fires. (A much more detailed discussion of the electromagnetic spectrum, its characteristics, and infrared uses is provided in an infrared course, see Appendix 3 for outline.)

B. Types of Detectors - A variety of detectors are available for sensing radiant energy (temperature) and they are used in a variety of infrared sensing equipment/systems. They can be classed into two main groups: thermal detectors and quantum detectors. Characteristics which must be considered in specifying or selecting detectors for IR equipment include: responsivity, time constant, detectivity, wavelength response, resistance, physical size, and operating temperature range.[5] It is important to note that these characteristics must also be considered in all other parts of an infrared instrument or system to assure compatibility and retention of the information sensed by the detector. Caution must also be exerted in determining any conditions associated with specifying the characteristics and/or what the test and measurement conditions include. These may be misleading or omitted in manufacturers' equipment specifications.

C. Types of Infrared Instruments/Systems - Infrared systems can be classified in various ways, e.g., passive or active, imaging or non-imaging, etc.[6] Passive IR sensors rely upon the natural emission of radiant energy which occurs in all objects and is directly related to the temperature of the object. Active sensors carry their own radiation source along with their receiver.[7] A common active sensor is a radar set, usually operated in microwave bands, not in the infrared bands, which transmits energy out and detects the energy reflected back to its receiver. All known IR systems being used for fire detection/mapping are passive systems.

Non-imaging systems provide an indication of the temperature of an object or area in either a qualitative (light, horn, etc.), quantitative (calibrated temperature reading), or relative (deflection of meter from an uncalibrated reference) manner. Imaging systems provide an image of the scene in the field of view and the temperature of objects or areas within the scene is deduced, usually in a relative manner, by the "brightness" of those objects or areas compared to the background. An imaging system thus displays the total scene and hot objects can be located based on their relationship to the total scene. A non-imaging system simply gives an indication of the temperature averaged over the field of view of the sensor. Non-imaging systems are relatively inexpensive, low performance instruments (see Appendix 4) useful by individuals for detecting heat differences nearby (20-30 feet) which might otherwise not be detected by eye. Since there is no image of the sensed area, the operator cannot be sure that a given area has been adequately covered.

Imaging IR systems provide an image of the covered area which is viewed at the sensor's display, on an accompanying video monitor, or on a hard copy printout, or some combination of the above. Video compatible systems can

also record the IR images for subsequent playback and may include audio annotation.

IV. EXAMPLES OF AVAILABLE IR SYSTEM/EQUIPMENT

Examples of the types of IR systems/equipment presently available for fire management use will be described below. The examples will follow the hierarchy shown in Appendix 4. Military systems will not be described because they are too expensive and also do not meet the requirements for fire mapping/detection systems.

A. Airborne IR Line Scanning Systems - IR line scanning systems provide the largest area coverage, best hot spot detection capability, highest image quality, and best overall performance of the various equipment in the heirarchy. Predictably they also have the highest cost and are the most complex. There are only two known airborne IR line scanning systems specifically designed for fire detection/fire mapping in the whole world. These are the systems contained in the two Forest Service twin turboprop airplanes located at the Boise Interagency Fire Center.

Airborne IR line scanners usable for fire management have also been built by Daedalus Inc. and used extensively in Canada. The Australians also procured a Daedalus line scanner in 1983 for use in remote sensing of resources and fire management. The Canadian services have been provided by Intera Inc. and are also available by contract in the U.S. The Daedalus systems are designed for general purpose thermal IR (or other spectral bands) mapping. They have a 77° TFOV instead of 120°, limiting their coverage of larger fires or areas. They also do not have the dual-band target discrimination circuitry and other features of the Forest Service systems. However, they can do a creditable job of fire mapping within their limitations.

Line Scanner Aircraft - Thermal IR line scanners are usually mounted in fixed-wing aircraft. The line scanners in most cases use an operator/technician monitoring and controlling the system at a console, thus, requiring some cabin space. The Forest Service planes were selected based on the operational IR needs of range, speed, operating distances, airfields available, and load capacity, as well as off-season use for other purposes.

Line Scanner Application - Line scanning systems provide the only effective method for completely mapping large fires (more than a few hundred acres) or fire detection missions over areas more than a few hundred acres. This high performance over large areas is possible because of the special features included in the line scanner design (see Appendix 5). All those features are necessary to achieve an acceptable performance level for fire use. The performance characteristics were identified during about 10 years of research and development and have been substantiated by over 10 years of operational use in the field. Military and commercial line scanners do not contain the dual-band detectors working into target detection circuitry as required for small hot spot detection and false alarm rejection. Military systems are usually AC coupled, which does not permit mapping terrain

features adjacent to large hot areas and does not include rapid processing of images on board the aircraft. Commercial systems do not have the wide total field of view (TFOV) coverage. The next level down the hierarchy, handheld imaging systems or Flirs, do not include a number of these features.

The Forest Service line scanners have 120 degrees TFOV. Because of the geometry, the edge spatial resolution is only about 1/2 the center resolution. The pilots attempt (normally successfully) to fly over the center of the fire. This gives the maximum resolution in the fire and its immediate surroundings. The additional edge area at reduced resolution is extremely useful in identifying terrain features for location of the fire and hot spots displayed in the imagery to the map. The pressurized planes can fly at 15,000 feet above ground level (AGL) or more if necessary. At 10,000 ft AGL, the cross coverage is 6.54 miles and a frame would cover over 27,000 acres. Thus, a 4-mile wide fire can be completely mapped with over a mile of unburned area showing on either side for location assistance. For comparison, a commercial line scanner might have a cross coverage of three miles and a frame coverage of only 5810 acres from the same altitude. A 21° x 28° Flir frame would only cover .7 x .94 miles or about 425 acres at that altitude and that is higher than normal Flir altitude. See reference 8 for a more detailed discussion on the available area coverage of line scanners and Flirs. The area coverage table, Section XII, shows the observed area at selected altitudes for different systems.

Line Scanner Operational Use - The airborne IR line scanners are available nationally (and have also been used extensively in Canada). They can be ordered through the National Interagency Fire Coordination Center (NIFCC) at Boise, 208-334-9407, FTS 554-9407, and come equipped with pilots and an IR technician/operator. Users need to provide a trained interpreter and liaison person. Because there are only two Forest Service line scanner aircraft, their use must necessarily be prioritized if there is need for more than two simultaneously. However, because of their speed and range they can often each fly several fires in a 24-hour period, depending on a number of conditions. Because of the seasonal movement of "fire season" around the various regions, the two planes can often support all needs throughout the year without serious conflict. Users should always formally request the IR services if needed and not "second-guess" their availability. This would greatly improve the "how-often-needed" records, and importantly, the users would often obtain the needed services even when they suspect they are unavailable.

Because of the complexity, need for specialized crews and technicians, and need for specialized maintenance and calibration equipment, these systems are operated and maintained by A&FM Operational Infrared Section on a national basis. The services are also available to other Federal agencies, states, and counties. There is no comparable service available from any other source (Government or private) because of the special design features of these IR line scanners.

The Daedalus systems are the only known commercially available airborne IR line scanning systems and have been in production for a number of years and

used literally almost world-wide for a variety of remote sensing applications. There are numerous optional features which should be technically reviewed and evaluated if purchase, lease, or contract use is considered.

Line Scanner Limitations - Line scanners are limited in versatility and flexibility because of their size, complexity, and need of a larger aircraft platform. The Flirs, used as handheld units in helicopters, can fly almost anywhere, land without airfields, make numerous passes, turn in a short radius, or hover over an area of interest.

Line scanners have always been limited in the ability to promptly deliver the processed hard copy image unless the drop-tube method can be used safely. The two RF downlink systems (discussed later) are an experimental step toward the eventual resolution of the near-real-time image delivery problem.

B. Forward Looking Infrared (Flir) - Flir is really a misnomer because they look sideways, backwards, or almost any other angle except when they are constrained by the mounting provisions to only look forward. None-the-less that is a commonly used acronym and will be used herein.

In this category the AGA 600-700 series Thermovision models, FLIR Systems Inc. Model 100, and Inframetrics models 525 and 445 will be grouped. They are characterized as being operable either handheld or mounted, require cryogenic cooling by liquid nitrogen (LN_2) or other means, operate in the 3-5, 8-14 micrometer, or a combination of those bands, are standard (NTSC) video compatible, are all commercially produced and marketed, and all have been used (and are in service now) by fire management agencies.

> AGA unit by Canada, references 9 and 10; FLIR Systems Inc. unit by California Department of Forestry (CDF), reference 11; Inframetics units by USDA Forest Service, A&FM, BIFC.

(Additional detailed technical data are available from the author or reference 7.)

Flir Aircraft - Flirs may generally be handheld or fix-mounted. The Forest Service and Canadian units are handheld. The CDF unit is mounted on a dedicated twin engine Cessna 337 fixed-wing aircraft. Forest Service units may be used in small fixed-wing aircraft or helicopters (or on ground vehicles or back-packs for that matter). They are normally used on helicopters. Forest Service contract helicopters are now equipped with a separate 28VDC power connector for Flir operation. The Forest Service units are suitcase-portable and can be operated from any available helicopter. This permits nationwide operation without selecting and requiring a unique aircraft to be present. Forest Service experience to date shows that the helicopter is usually the best aircraft for Flir use because of its flight maneuverability and available landing spots in remote locations.

Flir Applications - There are many fire related applications where Flir use is superior to other IR methods. For prescribed burns up to a few hundred acres, under established conditions, the Flirs are ideal for surveillance

and monitoring. They can show fire progress and status as time proceeds and can be quickly over the site of any suspected or actual unusual actions. Flirs can view the area after the burn is completed to assure that all hot spots are known and adequately treated prior to crew release. Proper and timely monitoring of prescribed burns by Flirs can help eliminate the embarrassment and cost of escaped fires.

Flirs used in conjunction with line scanners on active large fires can give a close-up IR "look" at crucial portions of the line. They can resolve whether the fire is contained within a firebreak or has crossed over when that may not be resolvable from line scanner imagery. They can be used to pinpoint spotting ahead of the fire perimeter and identify access conditions and routes to get to such spots. Line scanner flights may not be available (because of the limited number of aircraft and crews) more than once or sometimes twice per day on a fire. The Flir units can be used to update the last line scanner images along selected portions of the fire perimeter periodically or as needed. As the fire advances under the cover of a smoke screen the Flirs will "see" through the smoke and can be a valuable safety tool for planning crew placement or evacuation.

During mop-up operations Flirs can be used in direct support of crew activities. Flir operations in helicopters can identify hot spots otherwise undetectable by hand crews and literally talk them onto the location by radio. Thus hot spots can be found and taken care of and the crews moved to other locations, eliminating wasted time by crews in waiting and watching an area. Similarly, hot spots and potential trouble areas can be found and eliminated, precluding premature crew release and subsequent new breakout of the fire, which often results in substantial cost and loss.

A Flir unit may be used to identify, substantiate, and locate a known or suspected just-starting fire. In smaller areas of dry lightning strikes the Flir can determine whether any fires have started and if so their size and location. (For areas over a few hundred acres, an airborne line scanner should be used.) With the Automatic Lightning Detection System (ALDS) now operational that use could help preclude many of the lightning caused wildfires. These follow-up IR flights by line scanners or Flirs would also provide valuable information in validating predicted fire starts from ALDS data and predicted fire spread from computer models.

<u>Flir Operational Use</u> - Flirs are moderately expensive ($30,000 to $50,000) and fairly complex and sophisticated technologically. They require training to qualify operators (see Appendix 3 for training course outline) and experienced IR technicians and specialized IR test equipment for repair, annual maintenance and calibration. Some problems require supplier factory/lab attention. Although they contain some delicate instrument - quality components, the field reliability experience has been excellent to date.

Forest Service Flir usage is conducted in accordance with a Flir Operations Plan.[12] The units are maintained and operators are trained by the A&FM Advanced Electronics Group. The units are retained by trained operators from the participating regions during the fire season. The units with

trained operators are available as needed anyplace in the participating region by regional authority and nationwide via NIFCC dispatch.

For effective use, Flir requires a minimum of three people - the pilot, the operator, and a fire "observer". The observer is really the director of the flight and should be a member of the incident staff who is familiar with the area, the fire, and the purpose of the flight. The observer is responsible for recording the pertinent video and voice annotation of same to ensure that it is usable upon return to the command post. It should be emphasized strongly that descriptive voice annotation is very necessary - when back at the command post where the video cassette is played back for viewing. At that point there are none of the peripheral area or other awareness items to rely on; there is only what is seen and heard at the TV monitor.

Flir Limitations - As previously mentioned, Flirs are not suitable for detection over large areas or for large fire mapping. Table 1 shows coverage in feet, miles, and acres for Flir and line scanners. Figure 2 is an approximate scale drawing of a line scanner frame and a Flir frame superimposed on a theoretical 7,000 acre fire. A line scanner actually produces strip images - not frames - which would show even more area when "viewed" by the line scanners. Fires are also seldom in such a nice symmetrical shape and a real fire plan view would much more favor line scanner imagery. This example, though biased in favor of Flirs, clearly shows the limitations of trying to cover large areas with Flir imagery. Numerous passes would need to be made with the Flir and it is quite difficult, at best, to relate moving video to maps even when it is adequately voice annotated and freeze frame techniques are used. By comparison, a single pass with the line scanner aircraft covers the entire fire plus peripheral terrain features for orientation, and is available in hard copy strip film or, if transmitted, in a high resolution video individual still frame, not a moving standard TV resolution sequence. For detection missions over large areas, the advantages of the line scanners with target detection circuitry and automatic hot spot marking and alarms is even more dramatic.

Additional Features - Most Flir units have the choice of a white-hot or black-hot presentation. White-hot is most often used, but occasionally black-hot may provide more realism. Some units have isotherm marker capability, where all areas in the scene at a selected temperature will have a distinguishing mark. That is not usually needed for fire use but could be valuable on some non-fire applications.* Some Flirs include a "colorizer" which allows assignment of various colors to selected gray shades. It does not add any information to the scene but could provide a more vivid display in some cases. So far, that feature does not seem to offer an advantage worth its cost. Color TV has been used in conjunction with Flir units.

*The isotherm feature was very important when using the Flir units to locate previously undiscovered cave openings on the Lincoln NF near Carlsbad, NM. Cave air had a known constant temperature which was below the terrain ambients during June afternoons. When the pre-calibrated marks showed up, there was a cave opening!

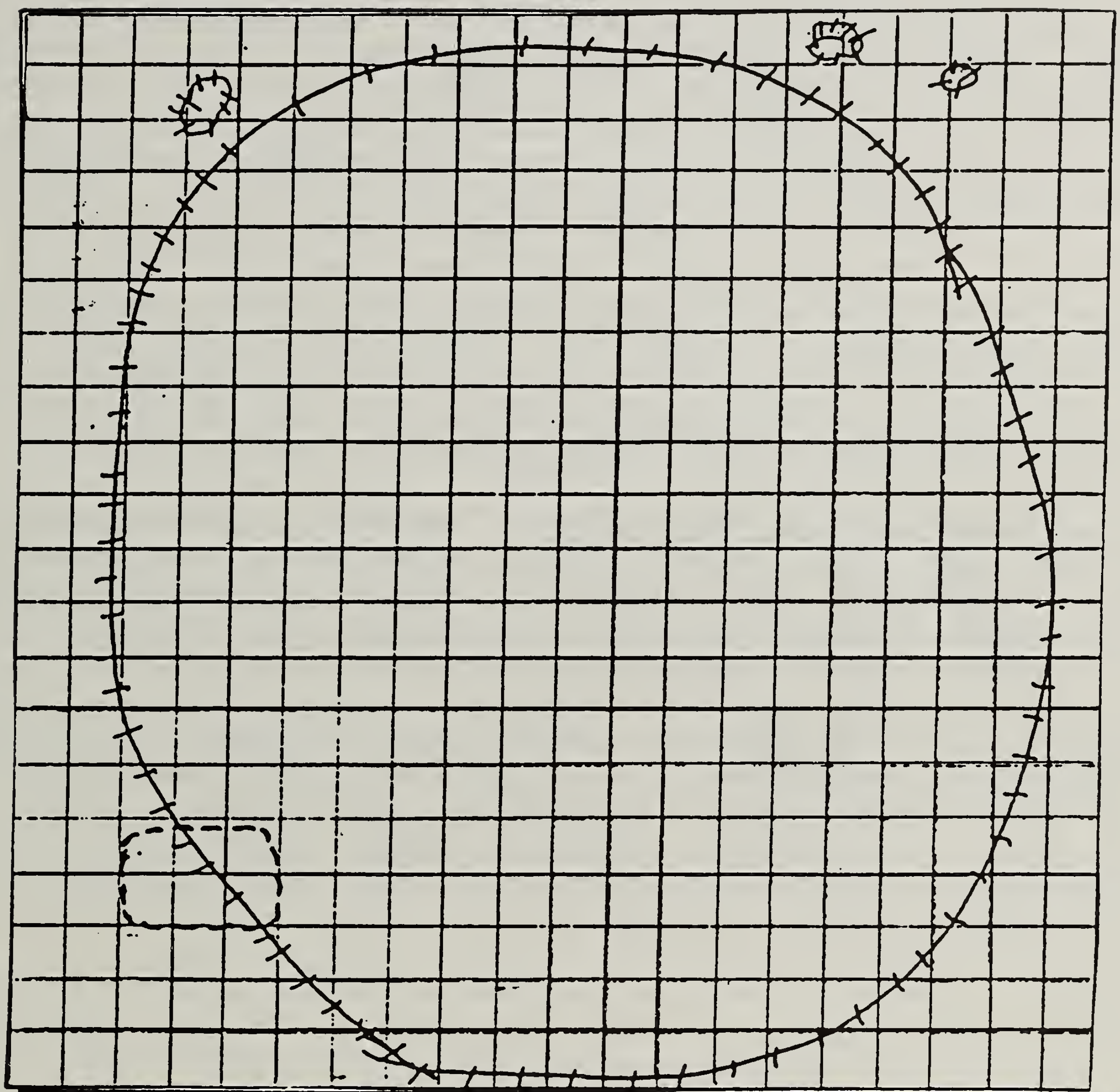

FIGURE 2. RELATIVE AREA COVERAGE
(From 6000 Ft Over Terrain)

———— Line Scanner Coverage ≈ 9800 Acres

-+-+-+-+- Fire or Area of Interest ≈ 7000 Acres

-------- FLIR (21 x 28°) Coverage ≈ 150 Acres

The color makes for a rather spectacular display and can sometimes be useful in helping identify locations or areas. Because color TV operates in the visible spectrum, it does not see through the smoke and does not sense temperatures - the two prime reasons for using infrared in the first place. With visible spectrum resolution and living color, it provides an interesting and dazzling display and may provide added intelligence for locating and positioning the fire. It also adds cost, weight, and complexity to the system. Additional trial flights are planned to evaluate the cost/benefits of using color TV in conjunction with Flir units.

Lease or Buy? - Several companies have Flir services available for lease with pilot and operator. As previously mentioned, Flirs are also commercially available for procurement. A lease-or-buy discussion is beyond the scope of this manual and is also very dependent upon the specific applications, rate of use, type of product, terms and conditions, technical specifications, and cost, etc. While most suppliers are honorable, proposals can be extremely misleading, usually as much in what is not stated as in what is stated. Some salespersons do not have a technical background, many do not understand Forest Service requirements, limitations, and operating conditions/constraints, and virtually all are zealous and usually convincing in offering their goods/services. It is highly recommended that a region interested in pursuing lease-or-buy of Flirs seek professional technical consultation from the A&FM Advanced Electronics Group at BIFC.

C. Other Handheld IR Imaging Units - Two other IR imaging units will be considered here. They are not usually called "Flirs" and the image quality is significantly less than that of the Flirs previously mentioned. One is the Hughes Probeye, a well known and extensively used unit; the other is the Pyro-electric type available from several manufacturers.

The Probeye - is usually used as a handheld thermal viewer without a means for recording the imaged scene. The direct-view display consists of a group of light emitting diodes (LED's) illuminating synchronously and proportionally to the IR radiation sensed by the detector array. The use of LED's accounts for the characteristic red display. The six element detector array is cooled with a cryostat from high pressure bottled Argon gas.

The Probeye is primarily useful to a person on foot for thermally viewing known or suspected hot spots in very small areas. It weighs approximately 7.5 lb. and viewing through a single eyepiece tends to be tiresome after a short time. The unit can be very useful when used by foot crews in mop-up operations, viewing slash piles after burning, or to otherwise detect hot spots or small hot areas not visible to the eye.

The Probeye is available commercially and has been used by a number of Forest Service regions. It is among the least expensive IR imaging units ($7000-$9000). It is easy to learn to use and factory or supplier maintenance is available.

Users should be aware that it uses high pressure Argon gas bottles as a coolant supply and establish sources and handling/shipping logistics plans in advance of lease/procurement/use. Users should also be aware that it is primarily a foot crew unit with a minimum quality image and small field of view. It operates in the 3 to 5 micrometer band which is good for hot spot detection but limited in providing background detail.

Pyro-electric detectors - along with thermocouples, thermopiles, thermistors, and bolometers - are classed as thermal detectors where absorbed radiant energy is converted first to heat, which in turn produces a measurement effect.[13] Unlike other thermal detectors, which have too slow a response time for use in imaging systems, the pyro-electric effect depends on the rate of change of the detector temperature rather than the actual value of the temperature. The pyro-electrics also have a very wide, uniform spectral range and good detectivity ratings. These characteristics permit their use in IR imaging systems.

The pyro-electric units, unlike the other imaging systems, do not require cryogenic cooling; liquid nitrogen, Argon gas, or refrigeration systems are unnecessary. This is clearly a logistical advantage. They are also small, lightweight, easy to use, and run on batteries. They use either pyro-electric vidicons or solid state pyro-electric arrays and thus eliminate the mechanically scanned optics. With these characteristics they would seem to be ideal imaging systems. However, there are some negative traits to counter those. Since the pyro-electric detectors depend upon the rate of change of temperature, a stationary viewed scene fades away. Consequently, the imagery must be kept in constant motion or provided with a chopping mechanism which tends to produce flicker. The constant movement also tends to show hot spots as streaks in the image or a spot with a comet tail effect, making location more difficult. In addition, thermal diffusion results in poor spatial resolution. When large hot sources are viewed, pyro-electric units may be "depoled," causing loss of image because of sensitivity reduction. When this happens, the unit must be "poled." Many units include an indicator of when poling is needed and a poling button to push. The poling operation takes approximately 30 seconds, which can be a considerable inconvenience when working around large or numerous hot spots. The image quality, although superior to Probeye (opinion), is still far below that of the cryogenically cooled, mechanically scanned, quantum detector systems (Flirs and line scanners).

The pyro-electric units are video compatible and a portable video cassette recorder (VCR) can be readily used for recording and subsequent review of the IR images.

The convenience and lack of cooling requirements make these attractive but the negative traits must be considered. Although some of these traits appear to be inherent physical characteristics, ways may be discovered or techniques developed to lessen their influence. Certainly pyro-electrics have seen considerable improvements in the past five years or so and more

may be forthcoming in the future. They are a little more expensive than the Probeye but certainly should be considered for use when contemplating equipment in that price and performance range.

Several companies manufacture pyro-electrics units and they are also available through distributors. Users evaluating them for lease or purchase should be aware that they must consider the effect of a number of technical specifications including detectivity, response time, poling, resolution, field of view, video synchronization and compatibility, spectral response, chopping arrangement if used, saturation conditions, responsivity, and others. Professional technical consultation with the Advanced Electronics Systems Group is recommended early in the consideration process.

D. Non-imaging IR Equipment - Non-imaging IR equipment does not, of course, provide an image of what is being viewed. It provides some kind of an indication that a heat source or temperature change exists in the area in which it is being pointed. The indicator can be a meter deflection, light, or audible noise. The operator must depend on his eyesight, judgment, and familiarity with the sensitive area of the unit being used to help determine where the hot spot is located.

The operator must also set the sensitivity level to trigger the indicator when a hot spot of a particular size and temperature is encountered. The operator will need to practice and check some hot spots at various distances and of different sizes and temperatures to get a feel for the level setting needed.

The non-imaging units are useful as handheld devices during mop-up or similar operations. They may be pistol-grip, flashlight type, or use a visual sighting aid. Some provide an average temperature indication of the area "viewed". Non-imaging devices are the cheapest and easiest to use but also have the lowest performance and usually require additional footwork to confirm what is really being indicated. However, they will sense hot spots which would not be detected by the eye and can improve the efficiency of mop-up crews.

The non-imaging devices range in price from approximately $600 to several thousand dollars and are available from several manufacturers or their distributors. Caution should be used in evaluating "IR viewers" or other IR devices and equipment because the technical specifications can be misleading and incomplete. Often too, an "IR" device may actually only extend into the near IR spectrum close to the visual portion. Those devices may have some applications but they are not thermal IR instruments and may have little or no use for fire purposes or even be confusing to the user. The spectral range and other technical specifications should be reviewed and understood in order to make a reasonable selection for an intended purpose.

V. OPERATIONAL CONSIDERATIONS

IR systems are available to Forest Service or other users by ordering through NIFCC dispatch for the airborne IR line scanners and handheld Flirs, or through regional or local control for handheld devices such as Probeye. Locally or regionally leased equipment or services may also be used from time to time.

The Forest Service airborne IR line scanners are dispatched in the aircraft with pilot, copilot, and IR technician(s). The using region provides a trained IR interpreter and IR coordinator. Details of times of flights, method of image delivery, airfield to be used, aircraft and crew available hours, lodging, ground transportation, ground equipment, and fuel for aircraft, etc., must all be considered.

Users are urged to request IR line scanner flights any time they are needed and let NIFCC dispatch work on availability and priority problems. It is reported that users often fail to request needed flights because of a perceived non-availability. Many times flights can be accomplished through prudent planning, scheduling, and routing even though the crews are indeed busy. Users should also recognize that occasionally because of limited resources, equipment maintenance or downtime, that it may be impossible to meet all requests in a hectic fire season. In such cases alternate times or methods may be suggested as options. But if flights cannot be arranged, next time try again -- and again. Don't give up.

Timely delivery of IR images following flight completion is often a problem. (See Figure 3 for a view of the three current methods of achieving image delivery and interpretation.) Hard copies of the images are produced on board the aircraft during the flights. Physical delivery is via drop tube or by landing at the nearest available airfield followed by surface transportation to the ICP. The former is fast and reliable but often cannot be accomplished for safety reasons. The latter can take so long that the delivery is not timely. Determining the method of delivery and probable time after flight required for delivery should always be considered during flight planning and scheduling.

Both Forest Service planes are equipped with a high resolution video transmission capability. Images in TV format can be transmitted to a fixed facility at Riverside, CA or to a mobile IR van. The mobile van was funded by Firescope and is physically located at Riverside. It could be driven to other regions or locations and set up for image reception at the ICP. When using the transmission/reception system, the plane first maps the fire and then transmits the images down. In the van the receiving antenna is rotated toward the plane (manually), the image frames are observed on a high resolution video monitor, and a black and white Polaroid picture taken of each transmitted frame. The Polaroid prints are the hard copies used for image interpretation and transposition of the fire location to maps by

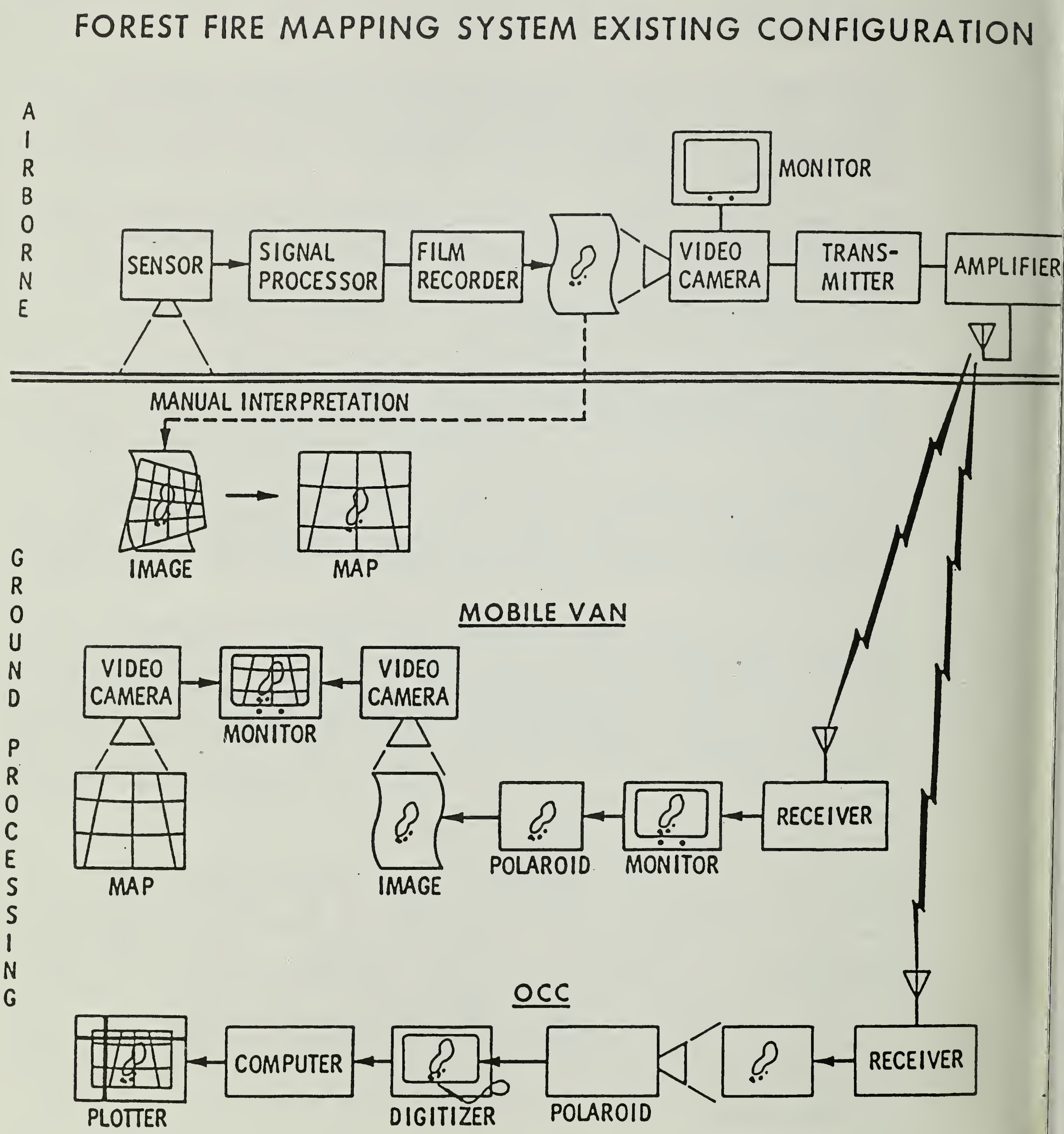

FIGURE 3
Image Delivery Methods for Line Scanners

the interpreter. The van also includes a "Linear Measuring System"* as an aid to speed up or enhance the transposition task, depending on other physical conditions of the area and imagery.

At the fixed facility, the Operations Coordination Center (OCC) in Riverside, the images are received and hard copies made similarly to the mobile van. The OCC has an automatic tracking antenna and a high resolution video hard copy recorder available. The image is then placed on a digitizer and the map in a plotter. A number of correlation points are entered from identifiable locations on the image and map. Based on those points, the mini-computer sets the scale factors. The fire perimeter and hot spot locations are then digitized and stored. The computer then drives the plotter so that perimeter and other information is plotted to scale on the map. This provides a quick and accurate means for transposing the fire information to the map, depending on the severity of distortions or nonlinearities in the IR image because of terrain features or aircraft attitude.

Two handheld Flirs are currently available from A&FM, BIFC in accordance with the "Handheld Infrared Imaging Systems Operations Plan," John W. Chambers, December 1982 (Reference 12). The two units are in the custody of trained operators from participating regions during the fire season months. Within those participating regions the Flirs are used, as needed, for prescribed and wildfire activities. Other regions may request the units with the trained operators through NIFCC. After fire season the units are returned to Boise for annual maintenance, check, and calibration. For special or non-fire applications, consult the Advanced Electronics Systems Development Group at Boise and the units will be made available with technical support as appropriate.

For fire use, the handheld units are used from a helicopter or fixed-wing aircraft. Contract helicopters are now equipped with a DC power connector for these units. They must have access to the atmosphere by removing a door or opening a window, since IR is attenuated by plexiglass. One or two persons from the fire staff, familiar with the fire, area, and IR objectives, are required in addition to the pilot and trained Flir operator. Interpretation of the IR surveillance is done by visual observation on board and by review of the voice-annotated video tape back at the ICP. Transmission of Flir imagery from an aircraft to the ground can be accomplished and is scheduled to be experimentally tried in 1984. The transmission capability is normally unnecessary from helicopters because of the usual close proximity of heliports to the ICP. The time gained in some situations would be minimal, usually an hour or less, and not cost-effective

*Manufactured by Measuronics Inc., Great Falls, MT

to provide. Radio communications from the helicopter to ground may be used for any emergency information relay to appropriate ground personnel. Helicopters flying the most productive paths and altitudes for fire surveillance may not always have line-of-sight required for the transmissions to the ICP.

VI. INFRARED MISCONCEPTIONS

From time to time various misconceptions or misunderstandings of IR characteristics and/or IR systems/equipment are noticed. A few of these will be briefly discussed here and the subject is treated in more detail in the Thermal IR course (Appendix 3).

Infrared is infrared is infrared. Actually a review of the electromagnetic spectrum (Figure 1) shows that "infrared" covers a significant portion of that spectrum. However, infrared photography uses a very small slice of the spectrum just below the visible portion. Thermal infrared is not infrared photography (Appendix 2). All the thermal IR instruments/systems in use for fire purposes operate in the 3 to 5 micrometer, 8 to 14 micrometer or a combination of those two bands. The vast remaining portion called infrared is used for other applications or not used much at all. It is thus necessary to know which portion of the spectrum is being referred to when simply labeled "infrared." Often an interesting instrument with some nice characteristics will be advertised as "infrared," which is technically correct, but the specs must be examined to identify whether it operates near the visible spectrum or in the thermal IR bands. Such instruments operating near the visible spectrum may be interesting and nice - but have little or no potential for fire management purposes.

This IR unit works better than that IR unit. This discussion will be limited to the thermal IR bands, so apples will be compared to apples. Obviously, as described in this report, there are different performance levels in the IR hierarchy. However, for instruments of the same class, the basic performance is subject to the same laws of physics and it is quite unlikely that "this one sees through smoke better" or "that one gives a cleaner picture," etc. In most cases where those types of remarks are made, the person does not have the experience or test data to reach such a conclusion. Two or more instruments can usually be compared to each other if they are operated side by side at the same time viewing the same scene. Even then caution must be observed because on a different day or viewing a different scene, with different atmospheric conditions, the results may reverse. Instruments can also be compared using special calibrated test equipment which is available at BIFC. Otherwise, random observations of image quality have little meaning. "Picture quality and picture impairment are purely subjective phenomena and have no absolute existence since no two viewers ever judge any given picture in quite the same way. Indeed, experience shows that even a single observer may well rate the same picture differently on two separate occasions in the same day."[14] Even with a known picture with one particular signal-to-noise ratio, the subjective reaction to picture quality or impairment varies widely among observers.

Beyond those two examples, other misconceptions are noticed occasionally. Many of these occur because of a chance observation, a unique good or bad experience, or misleading or incomplete ads or sales presentations. The suggestions are: don't jump to conclusions, be sure the conditions are known, use more time and more observations, discuss with others knowledgeable in the subject.

VII. SATELLITES AND U2s

Probably everyone in this country has seen satellite images (e.g., the nightly weather report on television). Also, many are aware of the U2 aircraft high altitude reconnaissance capabilities. These have been reviewed for potential to Forest Service fire management and for several reasons are not currently suitable or available. Appendix 6 discusses satellites and reference 15 discusses U2s.

VIII. LIMITATIONS AND OTHER CONSIDERATIONS

In the use of any of the types of IR systems/equipment available, there are some limiting factors (in addition to the technical specifications) which must be considered.

Infrared systems "view" the first surface in the line of sight. If a hot spot is behind a tree, log, dense foliage, etc., it will not be "seen" and hence not detected by the IR system. Rather, the IR unit will dutifully record the temperature of the tree, log, etc., which is directly in the line of sight.

Objects which are transparent to the eye may be opaque to infrared and vice versa. Ordinary window glass is a good example. Other materials will be opaque to the eye but pass infrared radiation.

The perceived temperature is always different from the actual temperature because the emissivity of all objects is less than one, the value of a theoretical perfect blackbody.

The sun is a good emitter of infrared as well as visible energy. The solar emitted IR radiation can be reflected and appear as hot spots or can be absorbed, resulting in heating of rocks or other objects which may then appear as hot spots compared to other background features.

Different bodies cool or heat at different rates. A body of water may appear cool during the day but when the ground cools off at night, the water may then appear warmer than the surrounding land. As this is happening, there will obviously be some crossover time when the temperatures will be about the same and the water body may be barely distinguishable.

Although most IR images are displayed as a black and white picture (video or hard copy), the image presented is a thermogram and usually appears somewhat different from a black and white photograph.

Some interesting thermal features may be observed which do not seem to make sense but are true thermal images. A cool pattern in the shape of a

car may show up on a sun-heated parking lot when no car is present. (It drove away 10 minutes ago and the temperature has not yet equalized.) One chair seat may be warm compared to the other four or five in the room. (Someone was sitting there earlier but left before you arrived.) So don't ignore a hot spot in the image which "shouldn't be there" based on visual information. It's probably there all right.

Infrared usually "sees" through smoke pretty well but not too well through atmospheric moisture such as fog or clouds. Sometimes the moisture content of smoke is high enough to cause heavy absorption losses and hence doesn't permit good IR "viewing".

Infrared sensors reveal information about areas or objects which cannot be sensed by any other means. Thermal IR systems sense and display the temperature of the viewed area (as modified by emissivity, atmospheric attenuation, etc.) within the limits and capabilities of the system design and performance parameters. We cannot look at a glass of liquid H_2O and determine its temperature. Unless there is adequate reflected light (visible spectrum energy), we cannot even determine that the water is present or absent. An infrared system can detect the presence in total darkness and (if properly calibrated) determine its temperature. Also, if we try to see something through dense smoke it may be totally obscured from our vision. Infrared systems can sense through smoke (within certain physical limitations).

In a fire situation, IR offers the potential for sensing hot spots and areas when the eye cannot determine whether they are totally innocuous or near an inflammable condition. Radiation of energy in the thermal IR bands is dependent upon temperature and requires no reflected light. Thus, infrared imagery is as effective in total darkness at night as it is in daylight. (Actually infrared imagery is better at night because of lack of solar IR band reflections and solar heated rocks, which can be misleading.)

The prime reasons for using infrared are that we can view areas through smoke or darkness when the eye would be incapable of seeing, and we can detect the temperature of areas, spots, or objects, which the eye cannot do.

Imaging IR systems, properly applied, have the potential for letting the fire management staff know exactly where the fire (and all associated hot spots) is located at any selected time - the time of the surveillance. IR images can provide an accurate history of fire movement and progress. IR systems cannot predict future activities, but accurate location knowledge is absolutely essential for the initialization of any fire rate of spread models which may aid in such predictions and for the validation of those models in the field.

IX. NON-FIRE APPLICATIONS

Non-fire applications are included in Appendix 7. The effectiveness of the presently available thermal IR systems has not been demonstrated for all

those listed. The conditions and situation pertinent to any selected potential use would need to be examined and evaluated to determine the probable value of IR sensing. Some applications might be better served by visual or IR photography. Some might require spectral analysis or multiband sensing. For any specific application a selection of the appropriate available IR system/equipment could be made when the desired objectives are known. The selection would be based on field of view, thermal resolution, spatial resolution, size and shape of area to be observed, temperature ranges, altitude above terrain, terrain features, special system features such as isotherm markers, image display method, and data evaluation. The proper IR system could then be chosen based on the technical performance capabilities of the various available systems. For certain applications it might be necessary to conduct an experimental flight to determine the probable effectiveness. In some cases, very interesting remote sensing tasks have been turned down because it was fairly obvious by analysis that there was only a low probability of success. Other tasks have been satisfactorily accomplished after analyses showed that they should succeed.

Future IR systems could be designed for accomplishing more of the non-fire tasks. Much of the design would be unchanged from a fire-only system. Additional spectral bands and/or spectral analysis capability could be used with changes mainly in the "front end" or sensing head part of the system.

X. PRODUCT INFORMATION

This section provides an overview of the types of thermal IR systems/equipment previously mentioned. It is not all-inclusive of all types. The information is believed to be current, but products do change from time to time. Costs are not included because many types of equipment have various optional features, costs do change, and GSA schedules and other discounts must be considered. Also, requests for quotes and procurement regulations must be considered. (A very general range of costs is provided in Appendix 4.) Detailed technical specifications are also not included because of the probability of misinterpretation, non-standard ways of specifying, and need for review of test conditions and methods associated with certain specifications for assurance that apples will not be compared to oranges. Reference 7 describes additional thermal IR equipment which is not applicable or has not been used for fire management purposes.

The Advanced Electronics Systems Development Group at Boise should be consulted to provide technical review, advice, and assistance to users considering procurement, lease, or other use of IR systems, equipment or services.

Military systems/equipment are not included because of their usual prohibitive costs.

Supplemental equipment such as instrumentation tape recorders, digital data storage equipment, transmitting/receiving equipment, video display units, image interpretation aids, and computer-aided image processing, are not included here because of their specialized nature, limited availability, and need for detailed technical review prior to implementation.

AIRBORNE THERMAL IR LINE SCANNERS

Airborne thermal IR line scanners are normally mounted on fixed-wing aircraft and require a trained operator.

Name/Model:	Fire Logistics Airborne Mapping Equipment(FLAME)
Manufacturer:	Jet Propulsion Laboratory, California Institute of Technology
Use:	Large area fire detection missions, large fire thermal mapping, large area mop-up surveillance, fire spread model initialization and verification, energy surveys, thermal resource investigations.
Features:	1 MRAD IFOV, 120°TFOV ± 10° for roll correction, Kennedy optics, dual band nominally 3-5 and 8-12 micrometers, DC or AC coupling, unique dual band signal processing for small (less than ½ square foot) hot spot (600°C) target detection from 15,000 feet above terrain at nadir, rectilinearization of displayed images, hard copy on dry silver film, video display in real time, digital image frame storage, edge and video event (hot spot) markers in hard copy with aural-visual alarms on board airplane. Video transmission to mobile ground unit.
Comments:	Operated by USDA-Forest Service, Aviation and Fire Management, Boise, Idaho. Available with plane, pilot, and IR technician by request from NIFCC, Boise, Idaho. Mounted on twin turbo-prop aircraft.

Name/Model:	TI RS-25
Manufacturer:	Texas Instruments
Use:	Same as FLAME
Features:	Same as FLAME except: less spatial resolution capability (2 MRAD IFOV and less than 1 square foot small target detection), no video display or digital storage. Hard copy is on rapid process wet chemical film--may be changed to dry silver film later.
Comments:	Same as FLAME

Name/Model:	Daedalus 1220, 1230
Manufacturer:	Daedalus Enterprises, Inc.
Use:	Fire mapping and detection, mop-up
Features:	2.5 MRAD IFOV, 77° TFOV ± 5° for roll correction, rotating axe blade mirror optics, dual band nominally 3-5 and 8-13 micrometers, threshold target detection, hard copy on dry silver film, event markers.
Comments:	A commercially marketed airborne IR line scanner. Also available for monthly or longer lease or on a pay-per-use basis from Intera Technologies Ltd.

Name/Model	Daedalus 1260, 1268
Manufacturer:	Daedalus Enterprises Inc.
Use:	Fire detection and mapping, mop-up, resource use
Features:	Can be used similarly to Daedalus 1220, 1230 for fire purposes but can also substitute a 10 channel visible band spectrometer for one of the IR bands for resource applications. The visible spectral bands are correlatable to those used on Landsat. Data can also be recorded on a digital tape recorder for subsequent playback and additional processing on the ground.
Comments:	Commercially marketed by Daedalus

Handheld IR Imaging Systems (Commonly called Flirs)

This category also includes Flirs mounted on either helicopters or light aircraft. Flirs require trained operators. The basic models of all Flirs listed are commercially available but will usually have special features, modifications, mounting provisions, auxiliary equipment, etc., for adaptation to fire use.

Flirs all require cryogenic cooling and use either liquid nitrogen or pressurized argon gas but most could be adapted to use either method (not both).

Uses for Flirs include: small area fire detection, surveillance, and mop-up; building heat-loss surveys; thermal resource investigations.

Since those uses are standard for Flirs, they will not be repeated for each unit. Flirs with isotherm features are especially useful in finding cave openings and certain other resource work.

Standard 525 line TV compatible means the output is viewed on video monitors and can be stored on VCRs for subsequent playback, all on commercially available equipment. Non-U.S. standard TV compatible (625 line, 25 frames) could also usually be procured for foreign country use if needed.

Availability - Flir units are generally commercially available for procurement from the manufacturers. There are also a number of companies which own various hand-held imaging systems/equipment and will lease or provide various IR services using that equipment. A list of such companies is not available and there seems to be considerable turnover in this field. Users contemplating such services are urged to seek professional technical consultation on their needs and the applicability of each of the myriad of available means to satisfy those needs prior to contractual action.

Name/Model: Inframetrics 525

Manufacturer: Inframetrics Inc.

Features: 2 MRAD IFOV, 14° x 18° TFOV, 3-12 or 8-12 micrometers spectral band, standard 525 line TV compatible. Very portable, normally handheld in a helicopter. Could be mounted. Has also been used in land vehicles and in a back pack. Uses either aircraft 28VDC or 12VDC for operation. Requires liquid nitrogen. Isotherm and line select features - valuable for some non-fire applications.

Comments: Two of these are managed by A&FM, BIFC and are readily available nationwide for fire and other uses. Forest Service contract helicopters have the DC power plug wired in and ready. The units require a trained operator. These units have been used extensively by the Forest Service in several regions and for various purposes.

Name/Model:	Inframetrics 445
Manufacturers:	Inframetrics, Inc.
Features:	2 MRAD IFOV, 21° x 28° TFOV, 8-12 or dual 3-5 and 8-12 micrometer bands, standard 525 line TV compatible, high spatial resolution - approximately 4 times that of Model 525. Requires liquid nitrogen.
Comments:	Improved spatial resolution over the Model 525.

Name/Model:	FLIR Systems 100
Manufacturer:	FLIR Systems, Inc.
Features:	1.9 MRAD IFOV, 17° x 28° TFOV, 8-12 micrometer band, standard 525 line TV compatible, high spatial resolution, requires pressurized argon.
Comments:	CDF has a unit mounted on a fixed-wing aircraft for fire use (See reference 11). They have been used considerably by the CDF.

Name/Model:	AGA Thermovision Models in 600, 700 series
Manufacturer:	AGA Corporation
Features:	1.9 MRAD IFOV, 7° x 7° to 20° x 20° TFOV's available, can be standard 525 line TV compatible when used with a scan converter.
Comments:	AGA has the widest variety in models and optional features of any manufacturer. They could provide almost any technically available feature by selecting the appropriate combination of models/options. There is also, of course, a wide range of prices which apply. AGA is a well established, world-wide supplier of thermal IR equipment and has probably produced far more Flir systems than all other commercial suppliers combined. Canada has used AGA systems extensively for a number of years (see references 9 and 10).

Name/Model:	Mini-Flir (Note the name was probably appropriate at the time it was developed, but it would not be considered "mini" now.)
Manufacturer:	Ford-Aeronutronic
Features:	2 MRAD IFOV, 30° x 40° TFOV, 8-12 micrometer band, standard 525 line TV compatible, mechanical refrigerator for cooling (doesn't need liquid nitrogen or pressurized argon).
Comments:	This unit is mounted on a Los Angeles County helicopter and has been used for fire purposes since 1975. It is a military (Army) unit adopted by the Forest Service, L.A. County, CDF, and others for fire use. It is the first Flir known to be used for fire by the Forest Service, starting in 1975. Advanced Flir systems have since been produced for the military but the costs are not competitive with Flirs which are now commercially available. The unit is still available for fire use in southern California.

Other Handheld Imaging Devices

This category includes units that produce a markedly lower quality image than the Flir units. They are generally easier to use and require less training but are lower performance. They are usually battery operated and can be used independently of a vehicle. They are useful for foot personnel but have also been used in helicopters. The pyro-electric types do not require cryogenic cooling.

They may be used for mop-up and for limited surveillance over a small area.

The Probeyes are available in several Forest Service regions. Various companies offer different types of devices in this category for lease or by providing a total service (operator and equipment). Notable suppliers have been Jay Doc Inc. and Red Eye Inc.

Name/Model:	Probeye, 600 series (There is also a new Probeye 4000 series but the technical features are not available at this writing.)
Manufacturer:	Hughes Aircraft Co.
Features:	2.2 MRAD IFOV, 7.5° x 18° TFOV, 3-5 micrometer band. Requires pressurized argon. Image is viewed through a monocle and is formed by scanning an array of light emitting diodes (LED's), resulting in the characteristic red display.
Comments:	Probeyes have been used extensively and are available in several regions.

Name/Model:	Videotherm Model 86
Manufacturer:	I.S.I. Group Inc.
Features:	2-20 micrometer range, standard 525 line TV compatible, poling indicator, low spatial resolution, no coolant required, pyro-electric.

Name/Model:	Pyroscan
Manufacturer:	Xedar Corporation
Features:	30° circular FOV, 8-14 micrometer band, standard 525 line TV compatible, low spatial resolution, no coolant required, pyro-electric.

Non-Imaging IR Equipment - These devices do not provide an image of the area under surveillance, but do provide an aural or visual means for determining a change in thermal energy from that area. Consequently they usually require additional close up inspection to determine just what has been detected.

They can be useful to foot crews doing mop-up or examining old slash burns for holdover hot spots.

There does not appear to be any manufacturer actively proposing these devices for fire purposes at this time. The 3M unit has been used in the Forest Service in the past. Three manufacturers are listed here for reference.

Name/Model: Heat Scanner 201MS
Manufacturer: 3M Company

Name/Model: Raytek Raynger, several models (very narrow FOV)
Manufacturer: Raytek Co.

Name/Model: Barnes Thermotrace and Instatherm
Manufacturer: Barnes Engineering Co.

XI. AREA COVERAGE TABLES

ALTITUDE (AGL)	FT.	MILES		FT.	MILES	TFOV IN ACRES
FLIR 14 x 18°						
		14	x	18		
1,000	246	.05		317	.06	1.8
2,000	491	.09		636	.12	7
3,000	737	.14		950	.18	16
4,000	982	.19		1267	.24	29
5,000	1228	.23		1584	.30	45
6,000	1473	.28		1900	.36	64
8,000	1965	.37		2534	.48	114
10,000	2456	.47		3168	.60	176
12,000	2947	.56		3801	.72	257
15,000	3684	.70		4751	.90	401
FLIR 21 x 28°						
		21	x	28		
1,000	371	.07		475	.09	4
2,000	741	.14		997	.19	17
3,000	1112	.21		1496	.28	38
4,000	1482	.28		1994	.38	68
5,000	1853	.35		2493	.47	106
6,000	2224	.42		2992	.57	153
8,000	2965	.56		3989	.76	272
10,000	3707	.70		4986	.94	424
12,000	4448	.85		5984	1.13	611
15,000	5560	1.05		7480	1.42	954
FLIR 30 x 40°						
		30	x	40		
1,000	535	.10		728	.14	9
2,000	1056	.20		1456	.28	35
3,000	1608	.30		2184	.41	81
4,000	2144	.41		2912	.55	143
5,000	2680	.51		3640	.69	224
6,000	3221	.61		4368	.83	323
8,000	4287	.81		5824	1.10	573
10,000	5359	1.01		7279	1.38	896
12,000	6442	1.22		8735	1.65	1292
15,000	8038	1.52		10,919	2.07	2015

AREA COVERAGE TABLE - Area versus altitude for various Thermal IR Imaging Systems

ALTITUDE (AGL)	FT.	MILES	TFOV IN ACRES
COMMERCIAL LINE SCANNER 77°			
1,000	1591	.30	58
2,000	3182	.60	232
3,000	4773	.90	523
4,000	6363	1.21	929
5,000	7954	1.51	1,452
6,000		1.81	2,092
8,000		2.41	3,718
10,000		3.01	5,810
12,000		3.62	8,367
15,000		4.52	13,073
FS IR LINE SCANNER 120°			
1,000		.66	275
2,000		1.31	1,096
3,000		1.96	2,465
4,000		2.62	4,382
5,000		3.27	6,157
6,000		3.93	9,860
8,000		5.23	17,528
10,000		6.54	27,388
12,000		7.85	39,438
15,000		9.81	61,623

XII. REFERENCES

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12. Hand-held Infrared Imaging System (FLIR) Operations Plan, John W. Chambers, December 1982.

13. The Optical Industry and Systems Encyclopedia & Dictionary for Engineers and Specifiers, The Optical Publishing Co. 1979.

14. Television Video Transmission Measurements, 2nd Edition, L. E. Weaver, 1977.

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APPENDIX 1

Engineering and Technical Disciplines Used in Thermal IR Systems

Physics
- Infrared
- Quantum
- Electromagnetic Radiation

Optics
- Reflective
- Refractive
- Lens
- OTF

Mechanical, Electro-mechanical, Electronics

Infrared
- Detectors
- Atmospheric Absorption
- Spectral
- Transmittance

Electronics
- Low noise amplifiers
- Op Amps
- DC coupling
- Bandwidth
- Scanning
- Display
- Modulation
- RF transmission/reception
- Antennas
- Video-TV formats
- Digital image processing
- Analog signal processing

Photography
- Film speed, exposure, development

Cryogenics
- Refrigeration
- Bulk-cool

APPENDIX 2

THERMAL INFRARED AND PHOTOGRAPHY

Thermal infrared (IR) line scanning systems are not "aerial photography or mapping" systems. Photography uses reflected natural or artificial light to directly expose sensitized film at the desired density. The thermal infrared systems produce IR images. An image is a representation produced by optical, electro-optical, optical mechanical, or electronic means where the emitted or reflected electromagnetic radiation from a scene is not directly recorded on film. In practice, thermal IR systems may not even use film at all and use video monitors, instrumentation tape recorders, video tape recorders, etc., as a means for storing and subsequent analysis of the images. Some confusion may exist because of infrared photography. IR photography is in fact an extension of conventional photography into the "near IR band" right at the edge of the visible spectrum. It too uses direct exposure of film.

Neither conventional nor IR photography provides the required information that thermal infrared imagery does because unlike thermal IR, photography is severely attenuated by smoke.

The authoritative MANUAL OF REMOTE SENSING makes clear distinctions between types of remote sensing and lists thermal infrared systems correctly under non-photographic sensors. There is no known practical photography application in the thermal infrared part of the electromagnetic spectrum.

The thermal infrared line scanning systems are also not mapping systems. "A map is a representation in a plane surface, at an established scale, of the physical features of a part of the earth's surface" -- from the MANUAL OF REMOTE SENSING. The IR line scanners use various scales and measures the relative temperature of a scene at a point in time. A map is intended for use where things change very slowly. The thermal IR measures temperatures which are continually changing. Physical features show up only because of their temperature or thermal emissivity differences on IR images. The IR systems are, in fact, dependent upon real maps for location of the fires and fire characteristics as shown on the images. Without real maps to relate to, thermal IR images would be of questionable value in most cases. A thermal IR image could more reasonably be called a temperature histogram at some point in time, rather than a map.

The thermal infrared systems are used primarily where severe loss of property, resources, and often lives are imminent, e.g., on active wildland fires. Conversely, aerial photography and mapping are normally used in benign or quiescent circumstances. The differences are far greater than the similarities.

JOHN R. WARREN
February 1981

APPENDIX 3

THERMAL INFRARED SYSTEMS
COURSE OUTLINE
ADVANCED ELECTRONICS SYSTEMS DEVELOPMENT GROUP

I. Classroom

1. IR Basics — Warren

Electromagnetic Spectrum
IR Discovery
Atmospheric Absorption
Emissivity
Reflectance
Transmission
Absorption
Detectors
Laws of Physics and Infrared
IR Optics
IR Sources

2. IR Instruments — Warren

Non-Imaging
  Spectrometers
  Thermal Indicators

Imaging — Gable
  Line Scanner
  FLIR
  Pyro-Electric
  Other

Hierarchy — Warren
  Price and Performance

Example Suppliers — Warren

3. IR Limitations — Gable

Atmospheric Absorption
First Viewed Surface
Solar Reflections
Low Δt
V/H

4. Resolution and Area Coverage — Warren

IFOV
TFOV
Line Scanner
FLIR
Other

5. Forest Service Background — Gable

   Research
   Operations
     Line Scanner
     FLIR

6. Taping/Recording — Gable

   Video
   Audio

7. Uses — Warren/Gable

   FLIR

     Confirmation/Update of Line Scanner
     Check on Hot Spots
     Check on Flare-ups
     Mop-up
     Verify Containment/Control
   Line Scanners
     Large Fire Mapping
     Large Area Detection

8. Other Sources — Warren

   Satellites
   U-2
   IR Photography

9. Cryogenics — Gable

II. Demonstration and Hands/On Training

1. Description of System Units — Warren

   Scanning Head
   Control Unit
   Video Monitors
   Video Recorder
   Power Supply

2. Connections — Gable

3. Liquid Nitrogen — Gable

   Handling and Storage
   Precautions
   Filling the Dewar

Appendix 3 (cont.)

4.	Power On and Initial Adjustments	Gable
5.	Special Feature Demonstration Polarity Line Select Isotherm Line Temperature	Warren/Gable
6.	Individual Operation and Viewing	Warren/Gable

III. Helicopter/Airplane Use

1.	Pre-flight Checklist	Warren
2.	Precautions	Gable
3.	Power and Connections	Gable
4.	In-flight Use	Warren/Gable
5.	Individual Operations During Flight	Warren/Gable

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APPENDIX 4

HIERARCHY OF IR SYSTEMS/EQUIPMENT

Trade or company names are used for examples only -- not endorsement. Prices are approximate. Equipment listed from highest performance downward. List is not all-inclusive but is representative. Prices include hard copy or video image productions.

Military Airborne IR Line Scanners	
Fire Mapping/Detection Airborne IR Line Scanners	$600 - 700K
Military Flir	
Commercial Flir (mounted)	$50K - 125K
Commercial Flir (handheld)	$30K - 50K
AGA Thermovision	$50K - 60K
Pyro-electric Vidicons (handheld)	10K - 15K
Hughes Probeye	7K - 9K
Non-imaging Handheld Heat Indicators	400 - 700

APPENDIX 5

FOREST SERVICE SPECIAL IR REQUIREMENTS

The Forest Service has some special infrared requirements which are not all available on military or commercial systems.

Dual-band detectors are required so the terrain features can be mapped (in the 8-14 micrometer band) and small hot spot energy acquired (in the 3 to 5 micrometer band) for processing in the target detection circuitry.

Rectilinearization of the imagery is required to aid in the interpretation and transposing of fire features to maps. The interpretation task is still performed manually and requires specially trained interpreters. The imagery scale is different in both the X and Y dimensions from the maps (and the imagery X and Y scales are not the same either). To add a non linear (non-rectilinearized) scale would compound the difficulty and increase the interpretation time, as well as decreasing the usefulness of the raw imagery for quick-look purposes.

Roll compensation and mileage markers to further assist in the image usefulness and interpretation.

DC response (rather than AC coupled systems) is required to enable the system to print terrain features of low thermal differences quickly following exposure to extended high temperatures of 600°C or more. Otherwise the washed-out imagery following such exposure would preclude the accurate determination of the fire front position with respect to firebreaks, roads, and other identifiable features.

Target detection circuitry is required to enable the system to detect very small hot spots which would otherwise be missed. Related to this are the special discrimination techniques used to almost eliminate false alarms. (Sending crews and equipment into remote areas over long distances and difficult routes to a non-fire is not a popular thing to do.) The special circuitry can detect less than 0.0225 square meter hot spots of 600°C against instantaneous terrain background variations between 0 to 50°C, from 5,000 meters altitude. (Note that this is accomplished with a 2 milliradian system which would have an IFOV of 100 square meters!) Since the small targets are not visible on the imagery, a special mark is printed which is offset a known distance from the actual spot to permit accurate location determination.

Rapid processing of imagery on board the aircraft is required so that the crew is assured that the fire was adequately covered, good quality images were produced, and to minimize aircraft and crew operational time. Many of the military and resource-oriented commercial infrared systems rely on processing film in a film lab some time after the aircraft has returned to the home base. That would nullify the effectiveness of the Forest Service missions, which have a basic need for developed and interpreted imagery at the fire camp within one hour of the time of flight over active fires.

A wide total field of view (TFOV) is required to cover large areas in a short time for detection missions, and to cover large fires in a single frame of imagery (rather than mosaicing) for mapping missions. A TFOV of 120° with another $\pm 10°$ for roll correction is used. As an example this provides approximately 11.4 kilometers across-track coverage from an altitude of 3300 meters.

APPENDIX 6

SATELLITES

A reasonable and often asked question is "why not use satellites?" At the present time, there are several reasons for operational, economic, and technological considerations.

The spatial resolutions from orbital altitudes are not as good as those from aircraft altitudes (which can be selected for varying fire sizes and conditions) even with the 2 milliradian system in use. The 2 milliradians IFOV could be reduced too, if that were necessary.

Mapping flights are scheduled by the fire staff to support operational activities. Satellites in orbit follow their own celestial trek which is oblivious to the earth situation. The geostationary orbit which makes a satellite always available over a large given area is too far out for adequate resolution with current technology.

Although technically achievable, the receipt of satellite imagery at the fire camp (via direct or indirect means) is either too expensive or time consuming.

The area of interest may be obscured by clouds from orbital altitudes. The aircraft can often fly beneath clouds to obtain the needed imagery.

The detection of small hot spots, as previously described, is not possible with any known satellites at this time.

The IR aircraft normally make several passes from different directions over a fire to assist in seeing areas of interest from different perspectives which aids the interpretation process. A satellite pass is fixed in time, direction, and orientation; what you see is what you get.

Satellite capabilities are monitored and some of the above dilemmas may be resolved in time. Satellite imagery is already useful in tracking very large fires in vast remote areas such as Alaska, where suppression actions may not be feasible or warranted.

APPENDIX 7

APPLICATIONS FOR THERMAL IR

FIRE APPLICATIONS

Fire mapping
Fire detection
Fire mop-up
Fire monitoring
Fire spread model validation
Fire spread model initialization
Restricted area campfire detection
Illegal immigrant campfire detection
Verification of lightning detection systems predictions of fire starts

NON-FIRE APPLICATIONS

Underground stream flows into rivers
Underground water sources
Warm water spring detection
Cooling pond efficiency and seepage
Water dynamics
Aquifer definition in glacial drift
Ice studies, mapping
Thermal effluent discharge studies
Surface and subsurface pipeline leak detection
Sewage disposal pollution detection
Septic tank seepage into waterways
Soil moisture studies
Ground water discharge into lakes, rivers
Volcano studies
Land use studies
Environmental impact studies
Geothermal studies
Artic geology studies
Glacier studies
Geologic mapping
Cave opening detection

Air quality studies
Methane gas seep detection
Smoke management studies
Airflow effects on vegetation near water bodies

Rooftop heat loss surveys
Building energy loss detection
Powerline surveillance

Animal census
Animal behavior studies

Search and rescue

Foliage effects of insects and disease
Foliage moisture content

GLOSSARY OF TERMS

This glossary includes nomenclature and definitions not necessarily included in the text of the Manual, but which are commonly used and accepted in infrared systems engineering practice. It is not all inclusive.

ABSORPTION:	The process by which radiant energy is absorbed and converted into other forms of energy.
ABSOLUTE TEMPERATURE SCALE:	The temperature scale named for Lord Kelvin, where absolute zero (where all molecular action ceases) is 0 Kelvins (K) or - 273.16°C (Celsius) or -459.7° F (Fahrenheit). The size of the Kelvin unit is the same as the Celsius degree. Liquid nitrogen maintains a temperature of 77K.
ACTIVE SYSTEM:	One which uses its own illuminating source of radiation, detects the reflected radiation and produces information from the reflection.
AIRY DISC:	The image of a point object focused by an aberration-free lens, consisting of a center of maximum intensity surrounded by alternate dark and light circles. The diffractions causing the airy disc limits the resolution in an otherwise perfect optical system.
ANALOG:	A form of data display or processing in which values are represented in graphic form such as curves.
APERATURE:	An opening through which radiation may pass.
ASPECT RATIO:	The ratio of the height to the width of a rectangular image or pictorial display.
ATTENUATION:	The reduction in available radiated energy as it passes through a medium such as the atmosphere or any physical object.
BACKGROUND NOISE:	The ambient noise present in a sensor, receiver, etc., with which a signal must contend for detection, measurement, and identification.
BANDWIDTH:	The range of frequencies over which a particular instrument or circuit is designed to function within specified limits.
BIT:	An abbreviation of binary digit, a unit of data that represents one of two possible values.

GLOSSARY OF TERMS (Cont.)

BLACKBODY:	An ideal body that completely absorbs all radiant energy incident upon it. It is also an ideal emitter which radiates energy at the maximum possible rate per unit area at each wavelength for any given temperature.
CALIBRATION:	The process of comparing certain specific measurements in an instrument with a standard.
CATHODE RAY TUBE (CRT):	A vacuum tube capable of producing black-to-white or color images by beaming electrons, synchronously, onto a sensitized screen. (The picture tube in TV sets, for example.)
CHARGE-COUPLED DEVICE (CCD) CHARGE-INJECTION DEVICE (CID) CHARGE-TRANSFER DEVICE (CTD)	Devices used in imaging, sensing, signal processing, and storage with special significance to IR line and area array developments.
COLD SHIELD:	A cryogenically cooled shield used in IR imaging systems to prevent extraneous radiation from reaching the detectors.
CRYOGENICS:	The science and technology related to extremely low temperatures, usually from absolute zero to 125K.
DC COUPLING:	A coupling method used to pass low frequencies down to DC permitting the DC level of the signal to be maintained.
DC RESTORATION:	A process in which the DC level of an AC coupled signal is clamped or reset to an absolute value while the detector is exposed to a radiative source whose output is constant. (In an AC coupled circuit the signal fluctuates about the average signal level.)
DETECTIVITY (D):	The inverse of the Noise Equivalent Power (NEP).
(D^*) pronounced D-star:	The detectivity referenced to an electrical bandwidth of 1 HZ and a detector area of 1 cm^2.
DETECTOR ELEMENT:	The small piece of radiation sensitive material located in the focal plane of the optical system which produces the electrical output signal.

DIGITIZE:	To convert an analog signal or image to a numerical digital format.
DISTORTION:	A general term referring to the situation in which an image is not a true-to-scale representation of the viewed scene or object.
ELECTROMAGNETIC SPECTRUM:	The total range of wavelengths (or frequencies) extending practically from zero to infinity, and including radio, microwave, infrared, visible, X-rays, and all other definable portions.
EMISSIVITY:	The ratio of the amount of radiation emitted by a surface to the amount of radiation emitted by a blackbody with equivalent surface area.
FIBER OPTICS:	The transmission of light through a glass or plastic rod or fiber by multiple total internal reflections. A fiber optic faceplate is made up of thousands of fibers arranged parallel to one another in a honeycomb design.
FORWARD LOOKING INFRARED (Flir or FLIR)	Refers to a class of IR sensors usually producing an output in a video display. Early military applications were for viewing scenes ahead of aircraft, hence the name.
GRAY BODY:	A radiating surface whose radiation has essentially the same spectral energy distribution as that of a blackbody at the same temperature but whose emissive power is less.
GRAY SCALE:	A calibrated sequence of gray tones ranging from black to white.
HERTZ (H_z):	A unit of frequency equivalent to one cycle per second.
INFRARED (IR):	Energy in the 0.7-100 micrometer wavelengths of the electromagnetic spectrum. Sometimes divided into near infrared (0.7-3.0), middle infrared (3-6), and a far infrared (6-15). Thermal infrared generally refers to the 3-15 micrometer bands or often to the 3-5 and 8-14 bands since the 5-8 band is severely attenuated by the atmosphere.

GLOSSARY OF TERMS (Cont.)

INFRARED DETECTION:	The process of detecting and locating small spots or areas of different thermal characteristics through the surrounding background features, e.g., small isolated fires over a geographic area.
INFRARED MAPPING:	The process of mapping the infrared emittance of an area to produce thermal images or thermograms of the area for display on film, CRT, or other means.
INFRARED PHOTOGRAPHY:	Photography in the portion of the electromagnetic spectrum just beyond the red end of the visible spectrum, usually defined as from about 0.7 to 1.0 micrometers or the useful limits of film sensitivities.
IFOV	Instantaneous Field of View - The area being sensed at any given instant in time. The IFOV is scanned cross track to the airplane flight direction in airborne IR line scanners. The IFOV is scanned in two directions in image framing displays (TV style) to create a two dimension scene.
IRRADIANCE:	Radiant flux incident per unit area on a surface.
ISOTHERMAL:	An area having the same temperature.
LIGHT:	Electromagnetic radiation detectable by the eye, ranging from about 0.4 to 0.75 micrometers in wavelength.
MICROMETER:	A unit of length equal to one-millionth (10^{-6}) of a meter.
MICRON:	Equivalent to and replaced by micrometer.
MINIMUM RESOLVABLE TEMPERATURE (MRT):	The smallest temperature difference in a standard periodic test pattern of a given spatial frequency that is resolvable to an observer over an unlimited viewing time.
MODULATION TRANSFER FUNCTION (MTF):	The ratio of the modulation in the image to that in the viewed object.
NADIR:	The point on the ground vertically beneath the prospective center of the lens or focusing optics of a sensing system.

GLOSSARY OF TERMS (Cont.)

NOISE EQUIVALENT POWER (NEP):	The radiant flux necessary to give an output signal equal to the detector noise.
PIXEL - PICTURE ELEMENT	A data element that defines the size of the resolution cell or area on the ground represented by the element. The magnitude defines the radiation intensity from the area.
RADIATION:	The emission and/or propagation of energy through space or a medium.
RADIOMETER:	An instrument for measuring the intensity of radiated energy in some band of the spectrum.
RECTILINEARIZE:	Correction for deviations in images which would otherwise distort straight lines or linear distances.
RESOLUTION:	A measure of the ability of a sensing system to produce a sharply defined image. Spatial resolution in an IR imaging system is usually synonymous with angular instantaneous field of view.
RESPONSIVITY:	The ratio of electrical signal output (voltage or current) from an infrared detector to the radiant power input over a specified wavelength interval.
TELEMETRY:	The science of sensing and measuring information at some remote location and transmitting the data to a convenient location for reading, recording, or further processing/formating.
THERMOGRAM:	A resultant photo or image illustrating in black to white tones the spatial relationship of the IR radiation temperatures of the different details in the scanned area.
TIME CONSTANT:	The time it takes for the detector to reach 63 percent of its final value after a sudden change in the irradiance.
TFOV:	Total Field of View - The total cross track length scanned by a line scanner, usually expressed in degrees. The actual length of the line depends upon the altitude or distance from the scene being scanned.
V/H:	The velocity to height ratio of the aircraft on which an IR line scanning system is mounted. Exceeding the maximum V/H for contiguous scanning lines will result in gaps in the coverage.

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